TOXICITY OF HEAVY METALS TO FISH: AN IMPORTANT CONSIDERATION FOR SUCCESSFUL AQUACULTURE

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Abstract

Heavy metals are toxic to man, animals and plants once safe limits are exceeded. Their ability to bioaccumulate in plant and animal tissues makes them particularly hazardous. Heavy metals are toxic to all aquatic biota and cause high mortality of fish larva, fry, fingerling and adult fish. They accumulate in the gills, heart, liver, kidneys, brain, bones and muscles of fish. The physico-chemical forms of heavy metals determine their mobility, availability and toxicity to fish. These metals enter aquaculture systems through various means (polluted water, storage facilities, fish feed, atmospheric deposition, etc) and constitute a factor detrimental to successful aquaculture. This paper reviews the mode of entry, transport and toxicity of some selected heavy metals to freshwater fish. Methods for the determination of these metals in water, fish and sediment samples are also presented. Ways of preventing their entry into aquaculture systems together with the safe limits of concentration of these metals in aquaculture systems are also included.

Introduction

Heavy metals are elements with specific gravity greater than 5.0 and are metals which can be toxic in small concentrations (Martin and Coughtrey, 1982). Heavy metals are introduced into aquatic systems through the weathering of rocks and soils; volcanic eruptions and various forms of human activities involving mining, processing or use of metals and or substances containing metal contaminants (Laws, 1981). According to Biney *et al* (2004), heavy metals are partitioned between water, sediments, suspended solids and aquatic biota in water bodies. Heavy metals tend to accumulate more in sediments than in aquatic organisms and water (Mansour and Sidkey, 2003) and as such sediments act as sinks and sources of supply of heavy metals to overlying water columns.

The global concern about heavy metals in the environment stem from their persistence, toxicity and bioaccumulation in the trophic chain (Welch, 1980).When heavy metals enter water bodies they change water quality, bind to sediments and accumulate in aquatic biota causing anaemia, disturbance of physiological functions and mortalities of fish (Post, 1983). Specifically, aquatic organisms experience histological and morphological changes in tissues; physiological changes like suppression of growth/development, poor swimming performance, changes in circulation, biochemistry, behaviour and reproduction (Widianarko *et al*, 2000). This adversely affects fish farming through decrease in revenue and profitability. Heavy metals also pose a serious threat to humans through ingestion of metal enriched aquatic organisms. According to Dougherty *et al.*, (2000), fish consumption is a major route of chemical exposure to man and heavy metals cause diseases like cancer, liver cirrhosis, renal damage, cardio-vascular problems, poor reproduction etc (Venogopal and Luckey, 1978) in man.

Mode of Entry into Aquaculture Systems

a) Atmospheric deposition: This can occur by way of dry deposition of heavy metals and their compounds into outdoor ponds. These metals go into solution and at elevated levels can harm aquatic biota. Metal compounds in the atmosphere dissolved in precipitation (rain, dew etc) can also be transported into outdoor fish ponds. However, this mode of entry is more important in highly industrialised areas.

b) Source of water supply: Heavy metals like arsenic and cadmium are contaminants of inorganic fertilizers via the production process. Others like copper and mercury occur in different forms in insecticides, herbicides etc. Heavy metals are also used by man in various processes and are also leached from refuse dumps. Surface run-off carries these metals and their compounds into waterbodies. Water from such waterbodies and surface run-off is thus, potentially harmful to fish in ponds where the water is channelled to.

c) Storage and piping systems: The material used to construct tanks and pipes for water storage is of immense importance. Dissolution of metals from the surface of such materials increases metal content in water used for aquaculture. For instance, cadmium is a contaminant of poly vinyl chloride (PVC) pipes and its compounds are used as fillers in some plastics. Acidic waters increase copper, lead and zinc solubility if tanks made with materials containing these metals are used to store such waters.

d) Fish feed: Heavy metals are natural constituents of the environment. Arsenic for instance, is present in all food in small amounts. Small amounts of cadmium are present in wheat/rice/maize proteins (Venogopal and Luckey, 1978). Heavy metal content in materials used for fish feed increases when metal containing herbicides/fertilizer are used to grow these materials and during the production process when these materials come in contact with metallic equipments and storage containers.

e) Excretion and Fertilization: Excretion involves the removal of toxic substances and products of metabolism from the body of animals in the form of faeces, urine, sweat, sloughed epidermal/mucosal cells etc. Heavy metals are excreted form fish by defecation and water in fish ponds (especially concrete ponds) should be changed periodically to reduce risk of bioaccumulation. Animal manure used for the fertilization of fish ponds also adds heavy metals to it. Excessive fertilization of ponds should be avoided due to risk of excessive metal content, oxygen depletion, high turbidity etc. The pathways for metal uptake by fish are through ingestion of metal laden materials and when metal laden water passes through the gill membranes.

Toxicity of Heavy Metals to Fish

Heavy metals can be divided into toxic (hazardous to living organisms) and essential (needed for normal body functions) metals. In between these are those with no known beneficial or toxic effects. Heavy metals like Arsenic, chromium, nickel and some iron compounds are carcinogenic while zinc, cadmium, mercury, lead and arsenic are teratogenic (inducing abnormal physical development and malformation of embryos). According to Zweieg *et al.* (1999), bioaccumulation is the process by which a chemical pollutant enters into the body of an organism and is not excreted but deposited in the organism's tissues. Heavy metals bioaccumulate more in the visceral tissues (liver, kidney, intestines etc) of fish than in the bones and muscles (Gbem *et al*, 2001) and induce diverse diseases in fish in addition to those outline above.

Toxicity of heavy metals is dependent on dosage (Oladimeji, 1983 and Eichler *et al*, 2006). Acute toxicity is as a result of large doses of a metal toxicant and symptoms appear rapidly and may result in death. Chronic toxicity is a result of prolonged exposure to small doses and symptoms appear gradually and may also lead to death (Venogopal and luckey, 1978).

Various geochemical and environmental factors influence metal availability/toxicity to aquatic organisms (Luoma, 1983). These include: (a) Metal concentration in solution. The higher the concentration in pond water, the higher the effect; (b) Solute metal speciation. The ionic nature of the metal determines its toxicity. For example, Chromium in the hexavalent ionic state (Cr^{6+}) is more toxic than in trivalent state (Cr^{3+}); (c) Metal partitioning among ligands within fish feed (d) Metal concentration in fish feed; (e) Influence of other metals. The effect of heavy metals on man and animals can be additive, antagonistic or synergistic (Underwood, 1979; Ellis *et al*, 1989). For instance zinc and copper are cadmium antagonists and so adverse effects of high cadmium intake can be reduced by above normal amounts of Zinc and Copper in the body; (f) Temperature. As temperature increases, rate of biological processes increase and may result in increase in metal uptake by fish; (g) pH. As pH decreases, more dissolved metals ions are produced. Ionic forms of heavy metals induce acute poisoning in aquatic animals leading to immediate fish kills while complex forms lead to chronic poisoning and bioaccumulation in fish tissue over a longer period (Ellis *et al.*, 1989, Baeyens *et al.*, 2005).

Safe Levels of Some Heavy Metals in Freshwaters

The levels above which heavy metals are potentially toxic to fish are shown in Table1:

Table 1. The levels above which some heavy metals are potentially toxic to fish.

METAL	SAFE LIMIT (mg/lit)	REFERENCE	COMMENT
Arsenic (Total)	0.34 (CMC)* 0.15 (CCC)	USEPA	
Cadmium	0.002 (CMC) 0.00025 (CCC)	USEPA	Water hardness, 100mg $CaC0_3$/lit
Copper	< 1.0	UNEP, 1999	
Chromium	< 0.5 (Total Cr) < 0.05 (Cr^{6+})	UNEP, 1999	
Iron	1.9	Duijn, 1973	
Lead	< 0.1	UNEP, 1999	
Manganese	1000 as $MgS0_4$	Duijn, 1973	
Mercury	0.0014 (CMC) 0.00077 (CCC)	USEPA	
Nickel	0.47 (CMC) 0.052 (CCC)		
Zinc	< 0.5	UNEP, 1999	

NB. The values on table I are for freshwater fish.

*The Criteria Maximum Concentration (CMC) is an estimate of the highest concentration of a material in surface water to which aquatic organisms can be exposed for a short time (acute exposure) without resulting in an unacceptable effect. The Criterion Continuous Concentration (CCC) is an estimate of the highest concentration of a material in surface water to which aquatic organisms can be exposed for a long time (chronic exposure) without resulting in an unacceptable effect.

Safe Limits of Heavy Metals in Edible Fish

The primary goal of aquaculture is to provide food for man and table 2 shows the safe limits of heavy metals in fish.

Table2: Safe limits of heavy metals in fish.

METAL	FAO(1983) limits in fish muscle (mg/kg)	MAFF limits in fish muscle. (mg/kg) *	WHO limits in freshwater fish (mg/kg)**
Cadmium	0.5	0.2	2.0
Copper	30	20	30
Lead	0.5	2.0	2.0
Mercury			0.05
Zinc	30	50	1000

MAFF = Ministry of Agriculture of the UK
Source: *Kebede and Wondimu, (2004.)
**Kakulu *et al*; (1987)

Measurement of Heavy Metal Content of Fish and Water

The foregoing shows the importance of monitoring heavy metal content of water used in fish farming. Again, since the wholesomeness of the fish sold to consumers is of crucial importance, fish produced by fish farms should also be examined for metal content. Methods of analysing heavy metals in aquatic ecosystems include Atomic spectroscopy (absorption/Emission/Fluorescence); colorimetry; electrochemical methods (particularly polarography and anodic stripping voltametry); Neutron activation analysis and x-ray fluorescence spectroscopy.

According to Biney *et al* (1994), the most common method for heavy metal analysis in African waters is Atomic Absorption Spectroscopy (AAS). Its advantages include; speed, sensitivity, simplicity, ability to analyse complex mixtures and low cost relative to other highly sensitive methods.

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